Undergraduate Computational Science and Engineering Education in the USA

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Major contributions from several others:
Linda Petzold, Angela Shiflet, Ignatios Vakalis, Kirk Jordan

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www.siam.org/about/pdf/CSE_Report.pdf

Also available via links from SIAM's Student page or CSE activity group page

The SIAM Report Working Group

- Sponsored by SIAM Education Committee
  - Similar report on Applied Math programs is “in the works”
- Working Group Members
  - Peter Turner (Clarkson University, Chair)
  - Kirk Jordan (IBM)
  - Linda Petzold (UC Santa Barbara)
  - Angela Shiflet (Wofford College)
  - Ignatios Vakalis (Cal. Poly. & State Univ.)

Definition of CSE

Unchanged from graduate report

A broad multidisciplinary area that encompasses applications in science/engineering, applied mathematics, numerical analysis, and computer science.

Computer models and computer simulations have become an important part of the research repertoire, supplementing (and in some cases replacing) experimentation.

Going from application area to computational results requires domain expertise, mathematical modeling, numerical analysis, algorithm development, software implementation, program execution, analysis, validation and visualization of results. CSE involves all of this.

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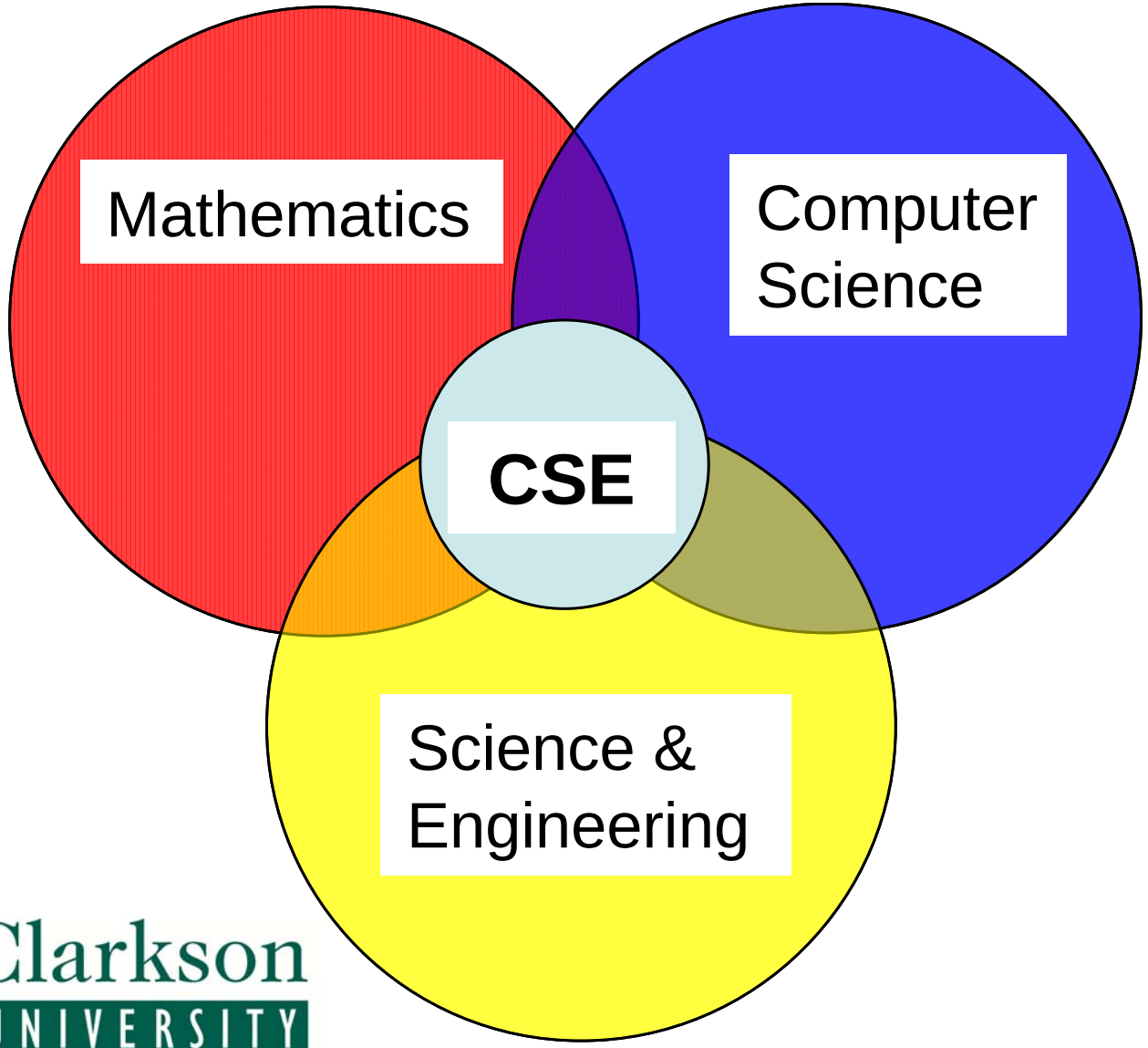
Or in picture form:



CSE is larger than the pure intersection of the three component pieces, but is nonetheless included in their union.

That is to say CSE provides, and strengthens, the bridges connecting those components but should not become a separate "island".

What CSE is, and is not

- CSE is a legitimate, important academic enterprise
- CSE focuses on integration of knowledge for development of problem-solving methodologies and tools
- CSE is *not* a part of applied mathematics or computer science
- CSE needs input/collaboration from the application domains

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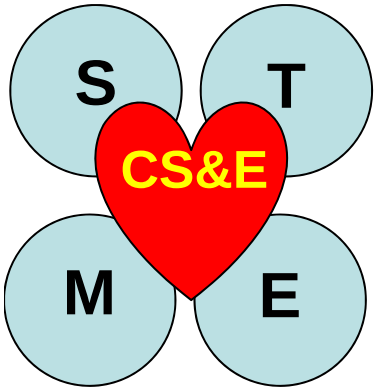
What CSE is, and is not

- CSE *differs* from science and engineering; it focuses on development of computational tools for solving complex problems
- Good undergraduate CSE programs respect and foster these properties and attitudes



CSE (and Applied Math) can be viewed as the heart of STEM – binding the components together.

The Working Group Report

- Nature of CSE Undergraduate Education
  - Introduction
  - Models of Programs
  - Examples
- The Value of Internships
  - Illustrated by examples
- Needs a CSE Education Must Address
  - An industrial perspective

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Flavors of Undergraduate CSE Programs in the U.S.

- B.S.
  - SUNY Brockport
- Minor Programs
  - Capital University
- Emphasis or Concentration
  - Wofford College
- B.S. in Computational X
  - X = STEM discipline or Finance
  - Computational Physics @ Oregon State

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Common Curriculum Content Components (1)

- Simulation and Modeling
  - Conceptual models, accuracy, use of modeling tools, assessment of computational models
- Programming and algorithms
  - A high level language, elementary data structures, analysis
- Applied mathematics
  - Calculus and differential equations, linear algebra, (discrete) dynamical systems
- Numerical methods
  - Errors, nonlinear equations, solving systems of linear equations, interpolation and curve fitting, optimization, Monte Carlo, ODEs, PDEs
- Parallel programming
- Scientific visualization

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Common Curriculum Content Components (2)

- Application domain content
  - At least one major application area of science or engineering
- Team-based projects
- Effective technical analysis and presentation
- Research or Professional Experience
  - Independent research, presentation of solution methodologies, internship
- Of course not all programs will cover all this in depth!

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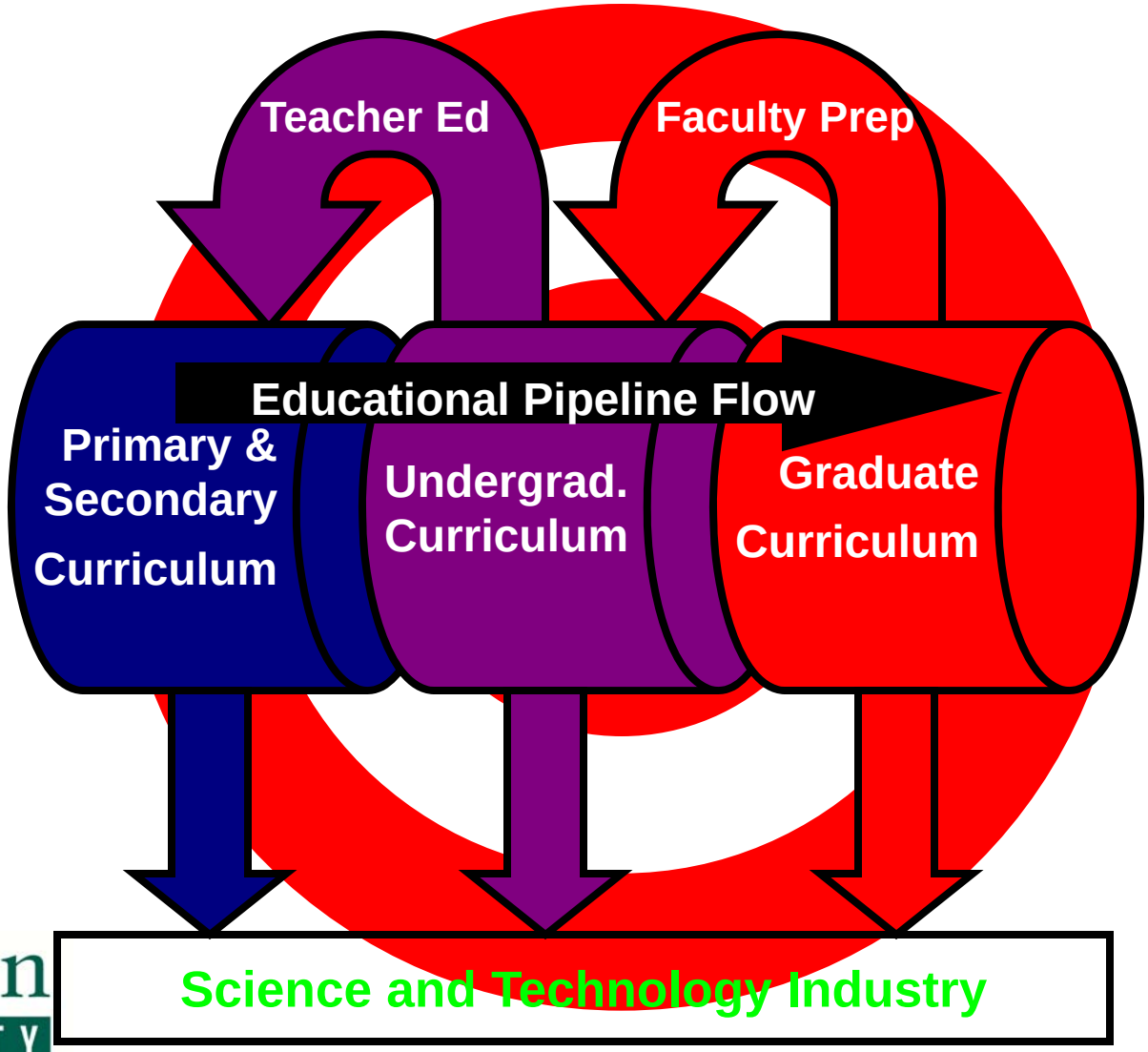
Why Target Undergraduates?



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PCAST Report: *Engage to Excel*

- Calls for one million additional college STEM graduates in the next ten years
- Identifies the “math gap” as an obstacle
- Calls for more relevant math education for K-12 and early undergraduates
- **Computational applied mathematics is an obvious answer!**

http://www.whitehouse.gov/sites/default/files/microsites/ostp/pcast-engage-to-excel-final_2-25-12.pdf

Motivational Factors for Developing CSE Programs

- Future jobs of technical nature require new skills directly related to computational science
- Computer science graduates do not have the modeling, mathematics and science background needed for future technical employment
- STEM fields are becoming more computational; science and engineering are now commonly done *in silico*
- **Provides relevance to mathematics programs**

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Motivational Factors for Developing CSE Programs

- Numerous reports and articles state the importance of computational science
  - *Engage to Excel* can be seen as the latest such
- Funding opportunities for developing computational applied mathematics curricula and educational materials focusing on the K-12 and undergraduate experience
  - SIAM-NSF Workshop *Modeling across the Curriculum*, late August 2012

Common Features of Educational Materials

- Self-standing, comprehensive modules
- Problem-based approach centered on applications from STEM disciplines
- Inquiry-based pedagogy, exploring the *what-if* scenarios
- Common paradigm:
  - *Problem → Model → Method → Implementation → Assessment*

Needs Undergraduate CSE Education Must Address

- The u.g. CSE Pipeline has many outputs:
  - Grad Schools
  - Industrial Opportunities
  - K-12 Education
- The basic skill set applies to all of these
  - Disciplinary and cross-disciplinary skills
  - Ability for independent learning
  - Team work
  - Adaptability and interest in problem-solving

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Needs Undergraduate CSE Education Must Address

- Professional Experience or Internships
- Projects
  - Interdisciplinary
  - Team-based, including team teaching
  - Extended projects help develop the perseverance needed for the workplace
- Breadth vs. Depth

Needs Undergraduate CSE Education Must Address

- Communication, too
  - Presentations at meetings
  - Educational outreach activities
- Career awareness is critical to recruitment
  - Simulation and computer-based engineering (e.g. Boeing 777)
  - All areas of engineering
  - Pharmaceuticals
  - Digital Media
  - Consumer products
  - …

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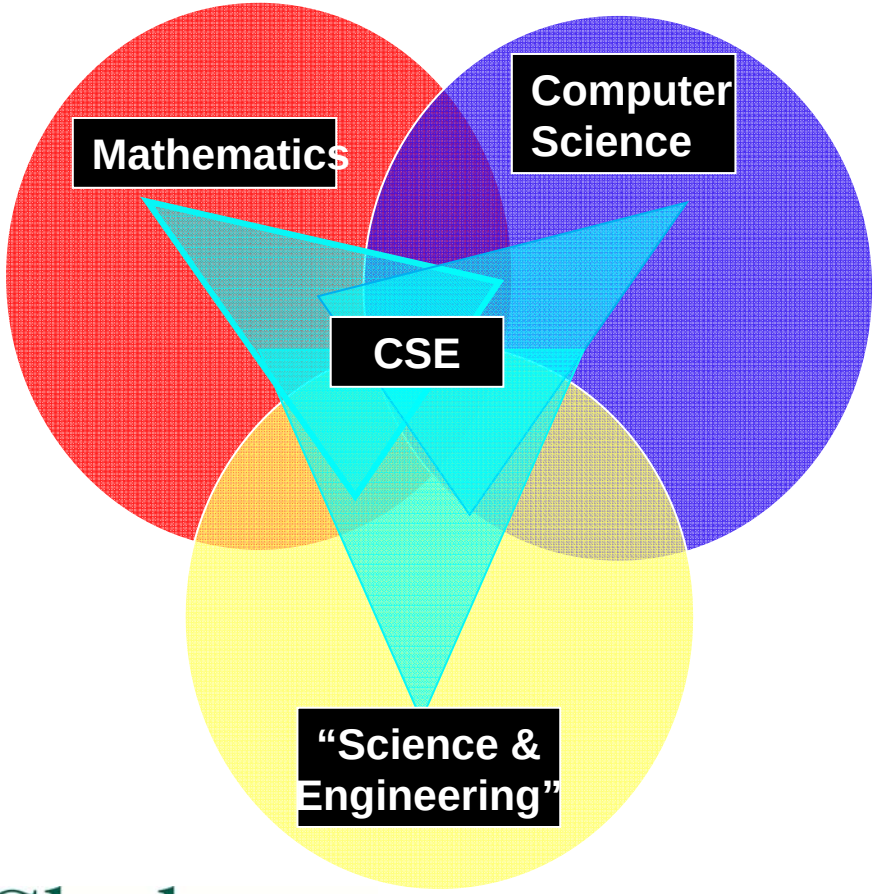
Professional Experience & Internships

- New ideas, techniques, applications
- Enhanced knowledge of CSE in practice
- Makes classroom education more meaningful
- Contributions to host's research
- Team work
- Different places
- Build confidence & Communication
- Contacts and Leverage

More on this from Angela Shiflet later

CS&E – An Industry perspective: What Industry Needs



- Strong foundation in a discipline
- Need computational skills
  - Not just MATLAB
  - Understand Error, Stability, Performance
- Need second discipline "expertise"
  - Speak another "language"
  - Provide added breadth
  - Transition to other problem areas
  - Willingness to Change – and to DRIVE CHANGE

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CS&E – An Industry perspective: What Industry Needs

- **Flexibility – Of employee:**
  - Good problem solving skills
  - Ability to work on variety of issues -- do what it takes to get the job done
- Good communication skills to
  - sell ideas/projects/concepts
  - get the point across fast
  - explain ideas
- Show high degree of organization

CS&E – An Industry perspective: What Industry Needs

- Persistence
  - Willing to stay with something to completion
- Ability to **"TEAM"**
  - Work with a variety of people and disciplines on different aspects of the projects
- Understand work as part of a greater world
  - Work outside one's discipline
  - Life long learning - driving curiosity and change

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Conclusions & Recommendations

- Many different models of undergraduate CSE programs can work
  - Local conditions probably dictate what is right for any one institution
- Many curricular items in common
- Many different objectives
  - Education, Graduate Schools, Labs, Industry

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Conclusions & Recommendations

Interdisciplinary collaboration must be an integral part of the curriculum and thesis research.

- Courses with multidisciplinary projects and presentations whenever possible.
  - Include different computing environments
- Participation in a multidisciplinary research team.

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Conclusions & Recommendations

- Internship at a National Laboratory, a Research Experience for Undergraduates (REU) program, or in industry.
- Conference sessions
  - Growth of undergraduate paper and poster sessions and computational REUs
  - SIAM CS&E Meetings have regularly featured such sessions
  - CSUMS sessions at Student Days here

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Conclusions & Recommendations

The Role of SIAM: Current, Future and Continuing

- Define the core areas and scope of this field
- Outreach to K-12 to produce better-prepared STEM students
- Help educate potential employers and managers on the nature and benefits of CSE
- Outline ideas for curriculum
  - Essential courses and desirable outcomes
  - "External fields" dependent on local conditions

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